SENSORS

Combined USBL and Inertial Navigation

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Sonardyne International

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Dynamic Positioning Committee
Marine Technology Society

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Combined USBL and Inertial Navigation

- an alternative and improved reference for DP

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Sonardyne International

DP Conference, October 2009, Houston

Agenda

1. **Motivation – why look at INS for DP?**

2. Sensors: USBL, LUSBL and INS
    - Concept of operation
    - Complementary characteristics
    - Integration – how it works!

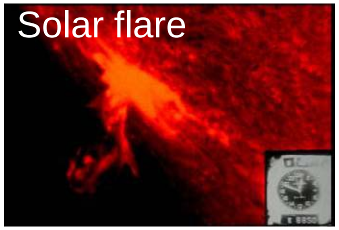
3. System configuration: Marksman DP INS
    - New Marksman LUSBL system (1. Oct 2009)
    - Select other components

4. Positioning performance prediction

5. Results from development trials

6. Conclusion

Motivation
- Why look at INS for DP?



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DGPS

- Sunspot activity / scintillation
  - GPS can be lost for ***long periods of time***

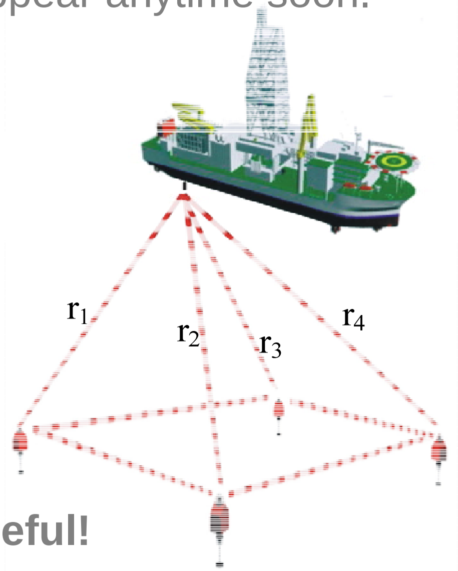
- Weak signals 10^{-16} watt/m2 ~ 40Watt light bulb @ 10.000 mile distance
  - A simple 1 watt jammer may destroy commercial GPS in a 100km radius
  - Unintentional jamming by faulty electronics has been seen.

- Improvements are pursued but issues are unlikely to entirely disappear anytime soon.

Acoustic positioning

- Aeration clouds, masking and increase in acoustic noise level
  - Typically ***short term problems***.

- LUSBL systems largely overcome these problems *through redundancy* but drop outs still occur.



=> Third reference type with different characteristics would be useful!

Motivation
- Why look at INS for DP?

Inertial navigation

- Inertial navigation is completely self contained and therefore ***inherently robust***
  - *Earth gravity and rotation is not easily disturbed!*

    => standalone INS is used for main navigation of
    e.g. nuclear submarines, ICBM's, and intercontinental airliners

- Continues output with very ***good short term accuracy***

- But drift is unbounded in the long term…

⇒ *INS complements acoustic positioning*
- what about combination ?

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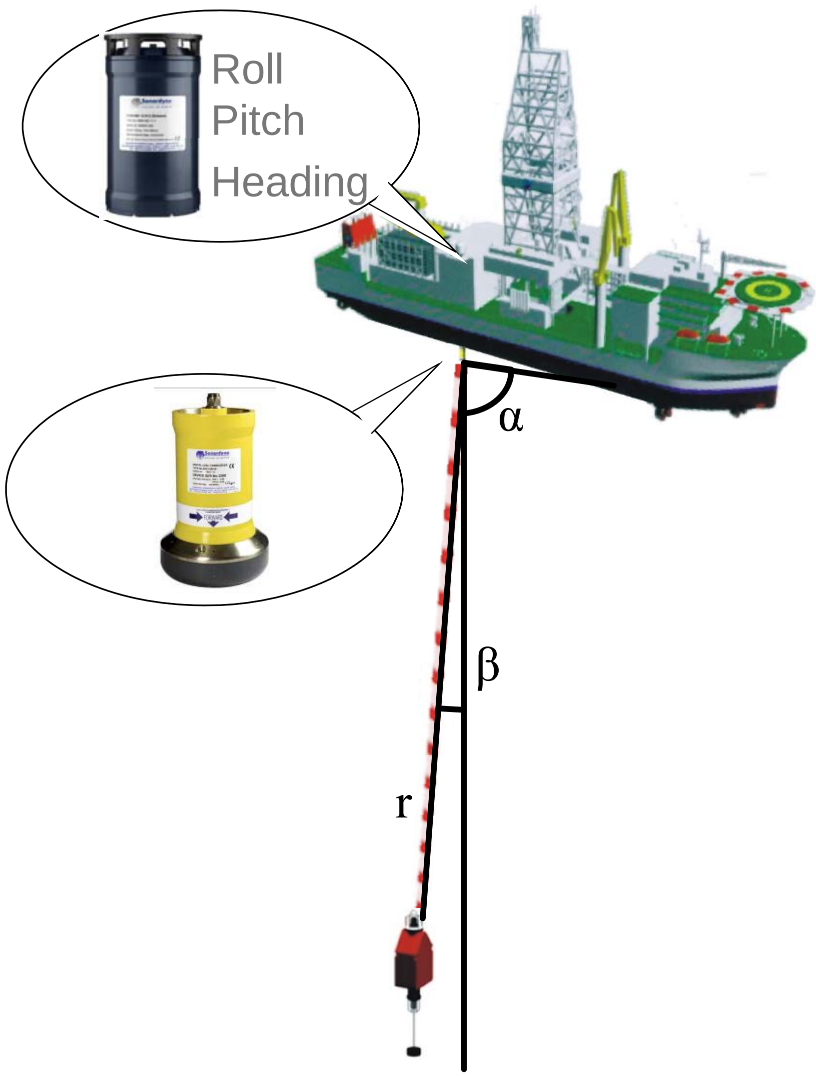
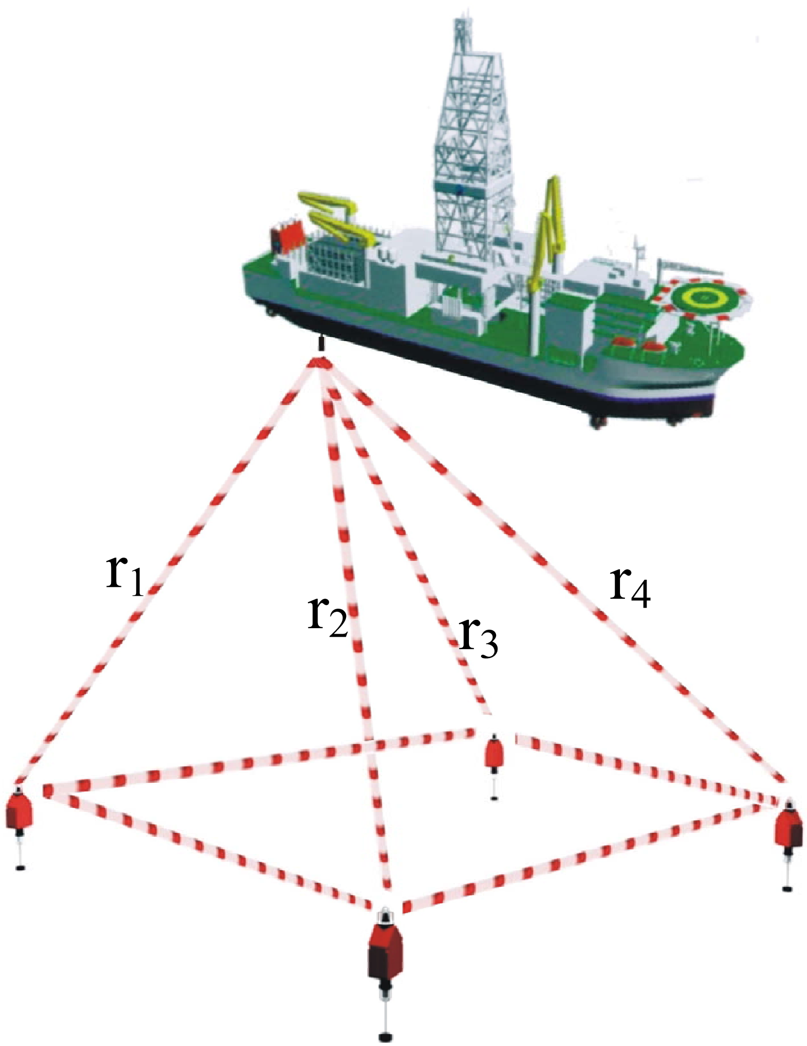
Ultra Short Baseline System (USBL)
- principle of operation



Positioning is based on measuring range and bearing from an acoustic transceiver to a seabed transponder and combining with attitude/heading.

- Accuracy decreases with depth:
  1-2m per 1000m depth (Lodestar AHRS)
- Modern AHRS is replacing gyro/MRU:
  0.12% slant range (6m, 1DRMS) has been achieved in 4950m water depth.
- Operationally efficient; a single transponder is placed close to boresight.
- Bearing measurement is somewhat susceptible to acoustic degradation.
- Update rate 3-4 sec in 2000m depth
  ~1Hz with ping stacking (deep water)

Long & Ultra Short Baseline System (LUSBL)
- principle of operation

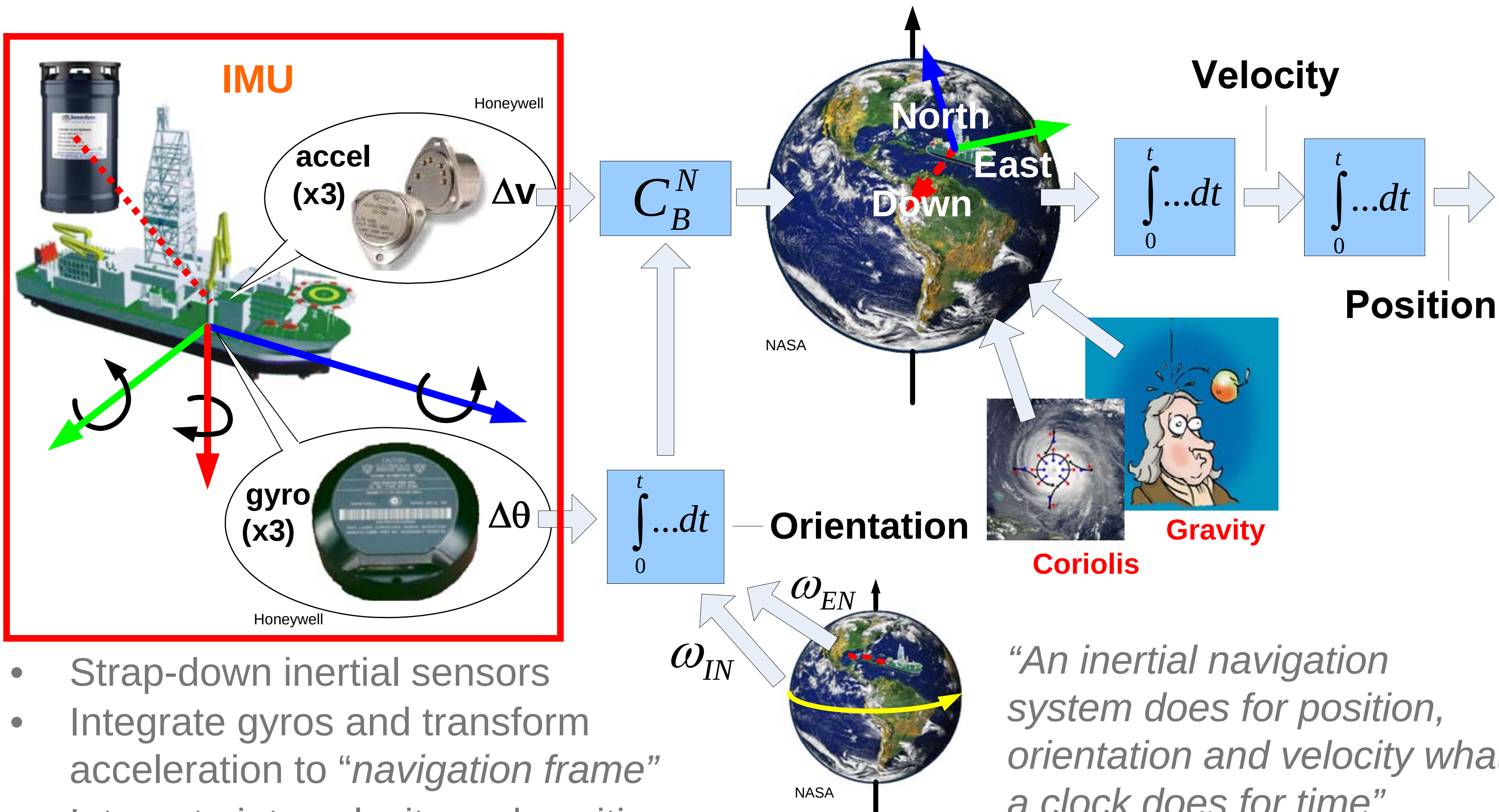


Positioning is based on measuring range and bearing from an acoustic transceiver to a seabed *array of transponders*.

- Redundant position solution dominated by robust range measurements.
- ~0.5m accuracy, also in deep water
- High precision Wideband acoustics allow transponders to be placed within ROV tether reach.
- Often installed in dual redundant or dual independent configurations.
- Update rate 4-5 seconds in 2000m water.

Inertial Navigation System (INS)

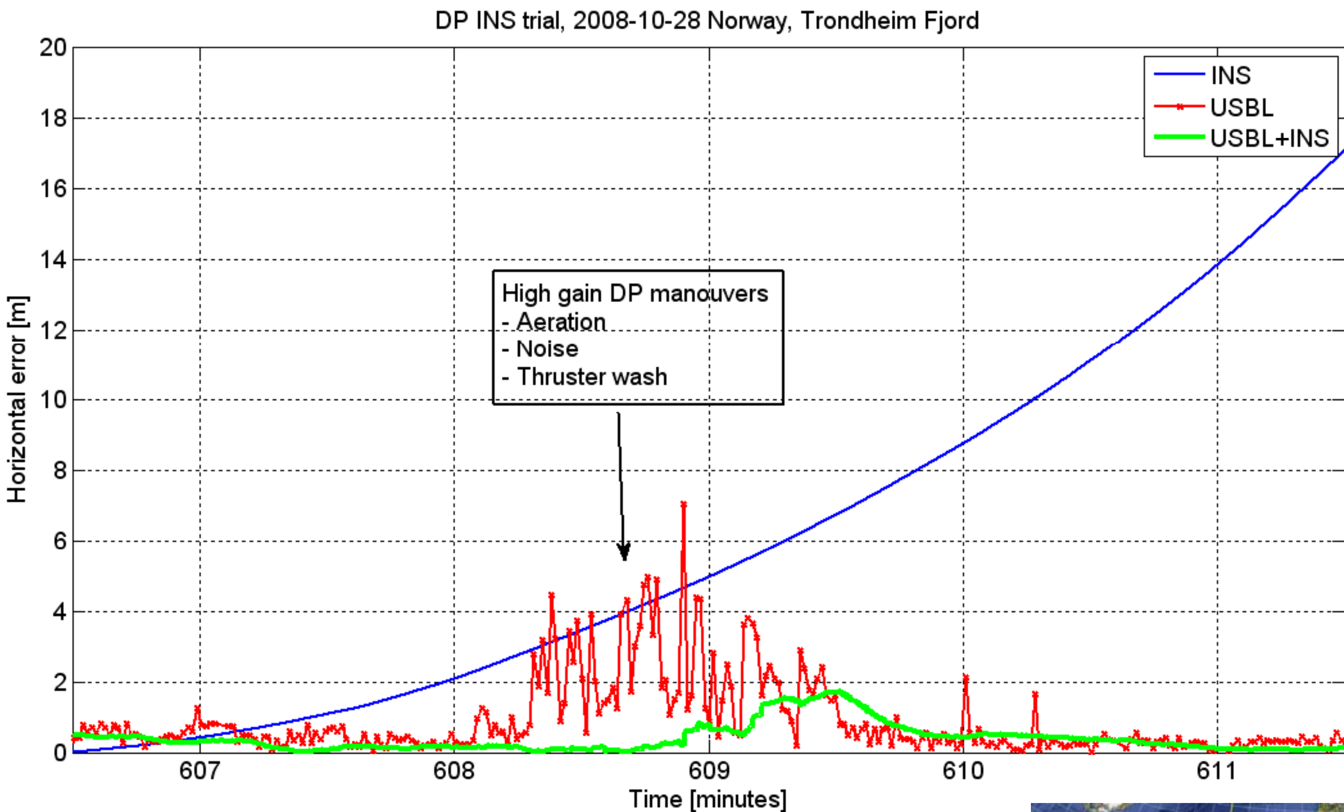
- principle of operation



- Strap-down inertial sensors
- Integrate gyros and transform acceleration to "*navigation frame*"
- Integrate into velocity and position.
- Gravity, Coriolis force, transport rate, Earth rate, …

"An inertial navigation system does for position, orientation and velocity what a clock does for time"

Combination of USBL and INS => **DP INS**
-complementary characteristics



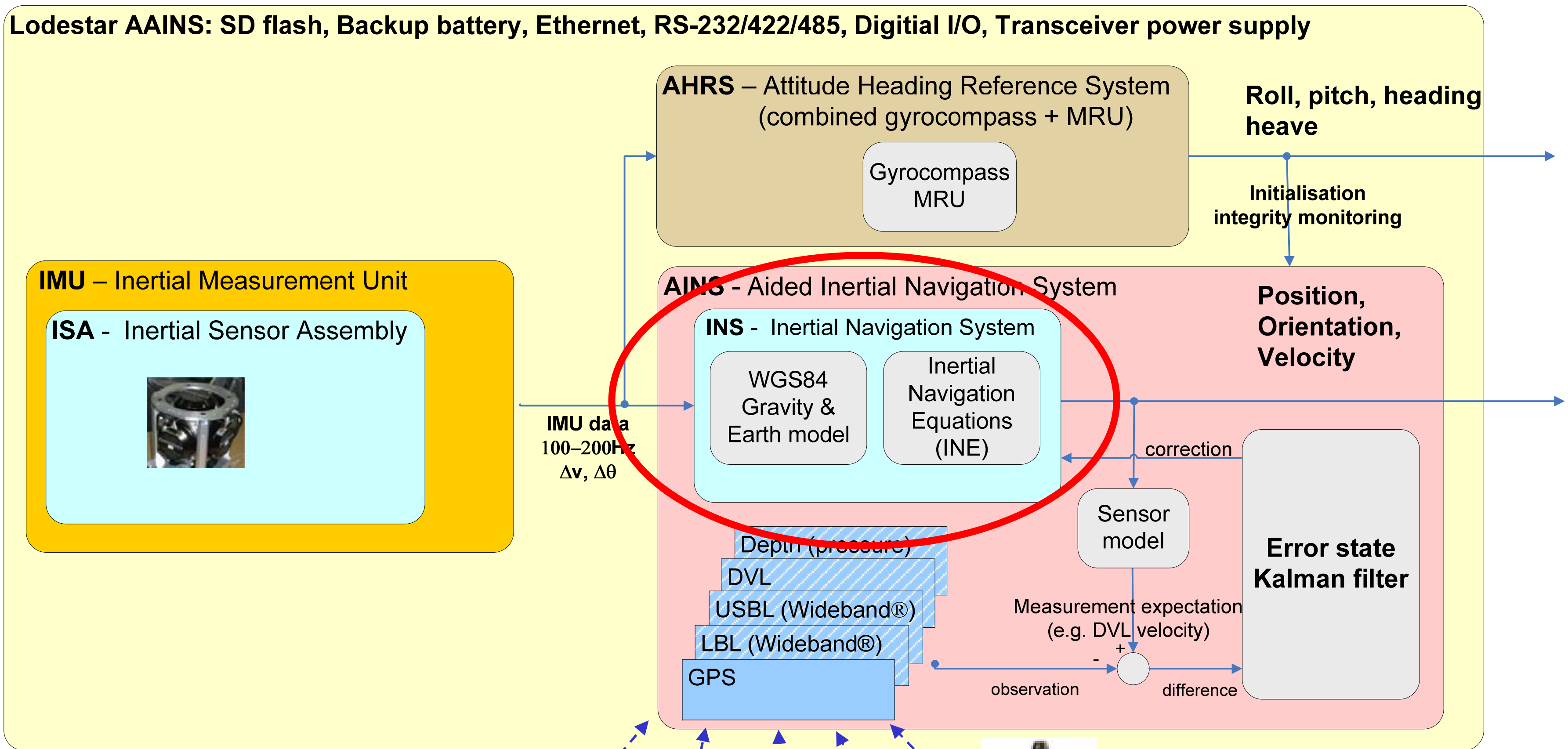
INS: Good short term accuracy but long term drift

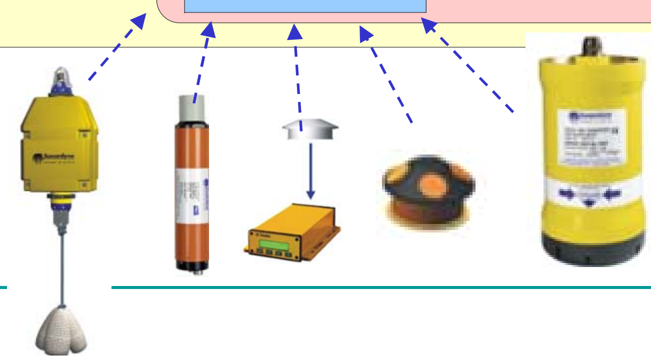
USBL: Higher noise and risk of drop outs but good long term stability.

DP INS: Best of both worlds

Combination of USBL and INS: **How is it done**?

- the generic *"Aided"* INS framework





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    - New Marksman LUSBL system (1. Oct 2009)
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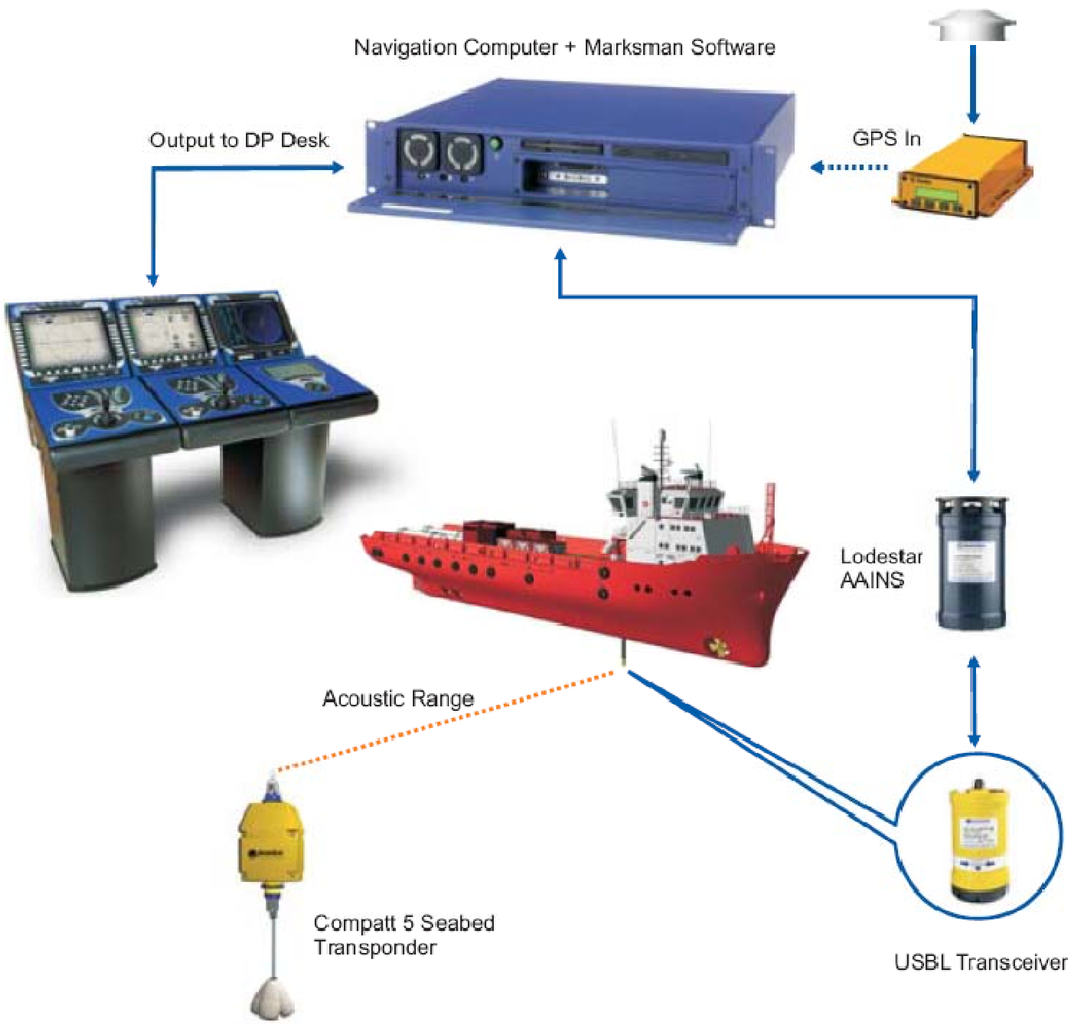
System configuration: Marksman DP INS



- The ***"Lodestar"*** **INS** is the core.
- USBL transceiver is interfaced and powered directly by INS (**perfect timing**).
- RS485/Ethernet + DC power from bridge (single cable)
- GPS is only required for initial installation and transponder position
- **New Marksman LUSBL system is the user friendly front end!**
- Also supports conventional LUSBL mode of operation

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System components: Marksman LUSBL

Design Philosophy - Reducing the operators workload

- DPO already has numerous computer based displays to operate produced by different vendors.
- Marksman designed from the outset to be easy to use.
- Display uses simple red/orange/green visual feedback to provide status ‘at a glance’.
- Windows XP operating system provides familiar look and feel.
- Optional touch screen display with a user interface that was designed with the touch screen in-mind.
- Marksman V1 was released and shipped on the 1st October 2009.

System components: Marksman LUSBL
Operational Benefits - Saving time and money

- ROV deployable arrays.
- Traditionally transponders are deployed at between 15 and 20 degrees from vertical.
- In today's' deepwater exploration this means a 2000m well would have a 700m array radius.
- **Wideband signalling** technology and **better calibration software** means Marksman can operate **7 degrees** from vertical.
- This gives an array radius of only 245m in 2000m.
- **ROV's can now reach the transponders** for deployment or battery change while the vessel remains over the centre of the array.

Transocean's Discoverer Enterprise
First operational deployment of Marksman LUSBL

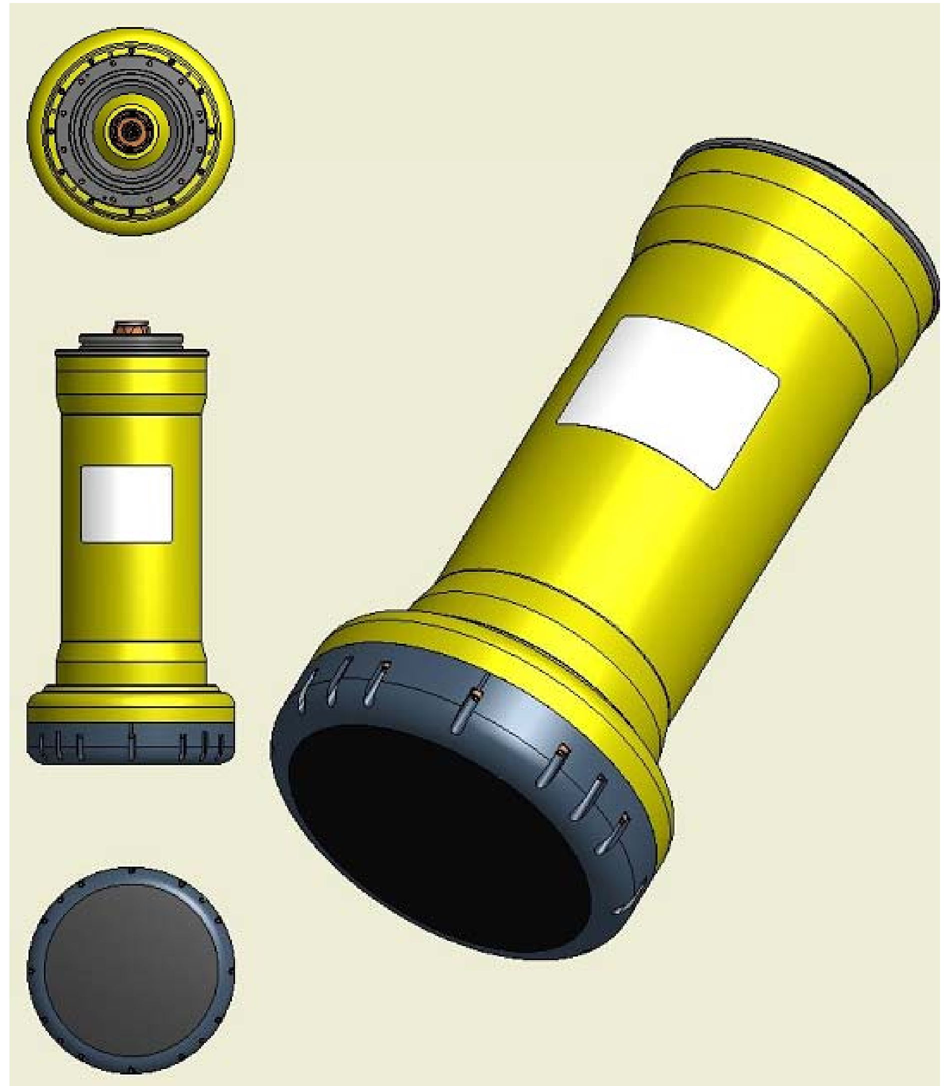
- Deepwater trials conducted in June 2009
- Lodestar used as AHRS
- Used vessels existing transceiver and transponders
- Installed and ready for use within 24 hours of arrival
- Performed Top Down calibration of the vessels transponder array
- Interfaced to Vessels DP desk
- Carried out DP manoeuvring tests

System components: Deployment machine, USBL transceiver and INS

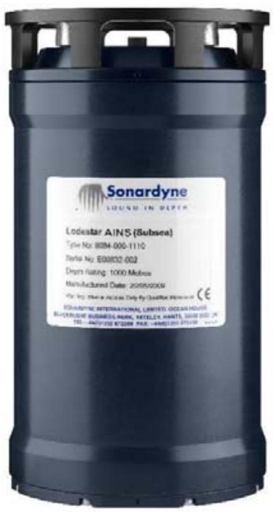
Tight mechanical integration to ensure stability between INS and USBL

The future?

Even tighter integration?



System components: Lodestar Acoustically Aided INS (AAINS).



<u>Key Lodestar features:</u>

- **Purpose designed Marine AHRS & INS, IMO certified (DP)**
- Highest performance (non-military) inertial sensors.
- Proven immunity to temperature change and vibration.
- Good sensor stability, important for near stationary applications
- **Inertial sensors: 300-400,000 hrs *proven* MTBF**
- Internal back-up battery – no loss of power.
- 32GB SD internal data storage for improved diagnostics and support.
- Internal INS computations
  - Added robustness
  - Better timing
  - No loss of IMU data
- Transceiver PSU
  - Simple installation

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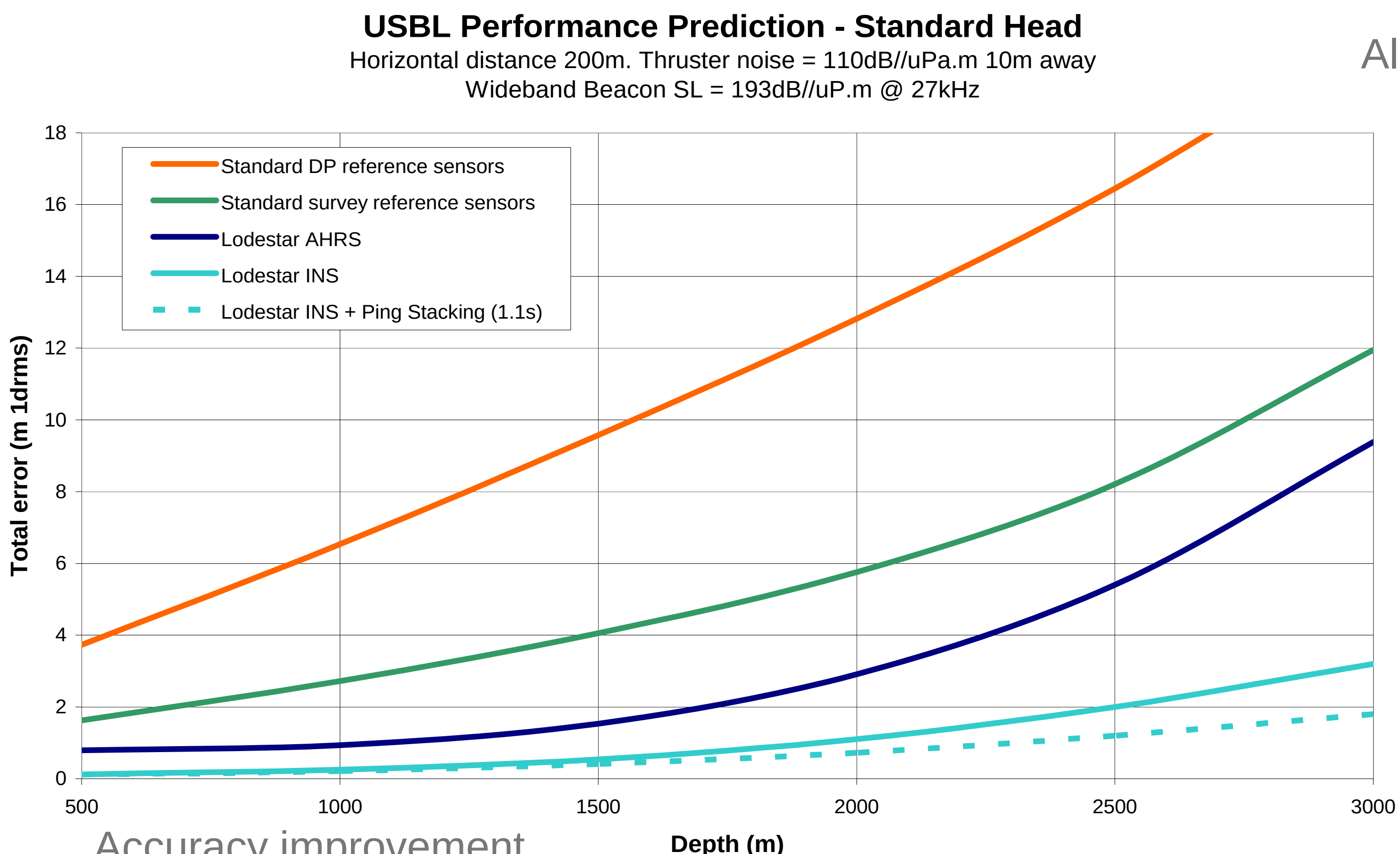
Performance prediction: Wideband USBL and DP INS



All values 1DRMS

Accuracy improvement

– x10 relative to conventional USBL for DP (standard gyro / MRU)
– x3 relative to state-of-the-art USBL: ~**1m accuracy @ 2000 m depth**.
– Further potential!

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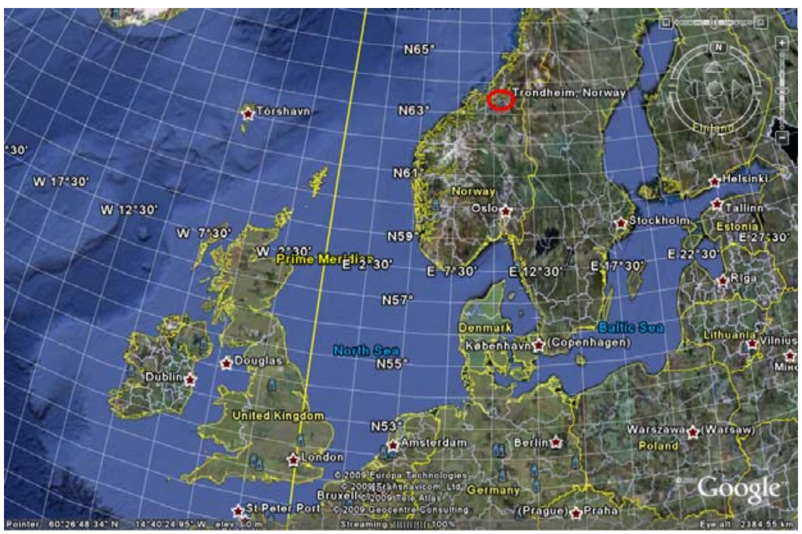
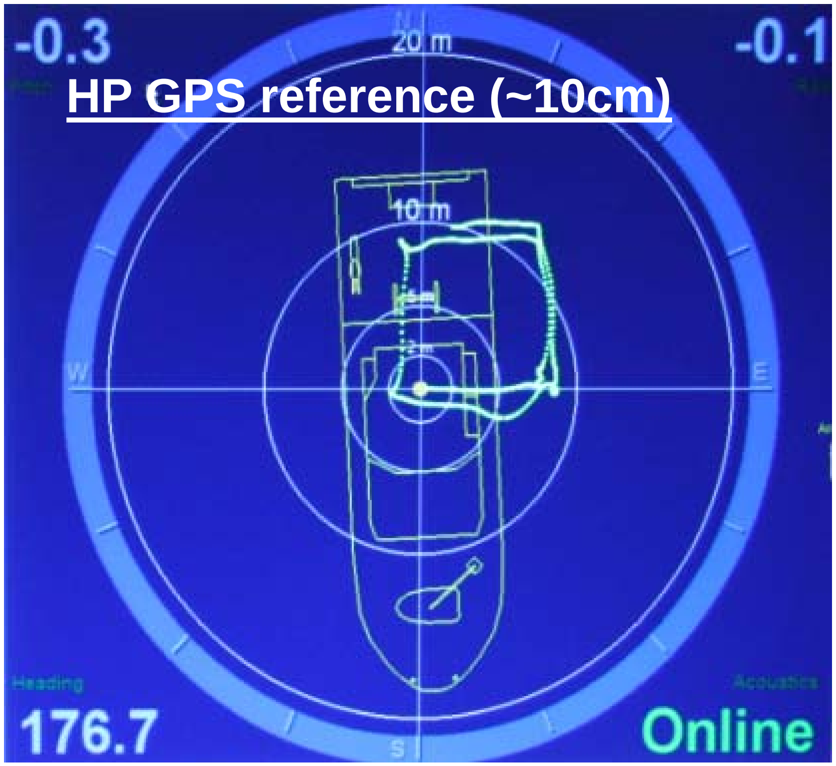
DP INS trials – experimental results
- 26. October 2008, Trondheim Fjord, Norway, sheltered 500m water depth



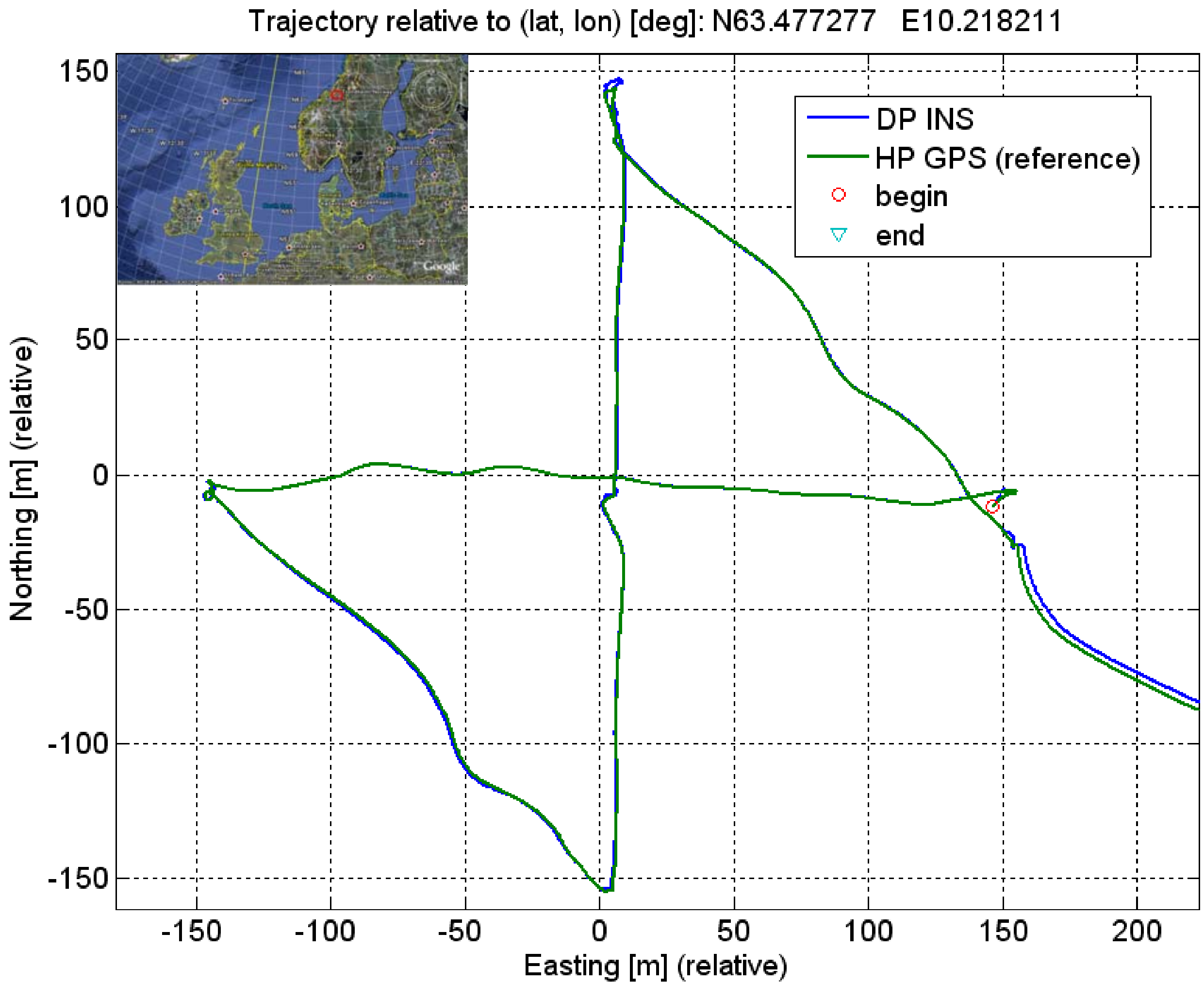
DP INS trials – **10x10m box manoeuvre**
- 26. October 2008, Trondheim, Norway



Pushing the limits:

- DP: 10 x 10 meter box (high gain)
- 1 Transponder, 500 meter depth.
- 20 second interrogation cycle
- Shallow over the side USBL transceiver
  - *Thruster noise (max power specified)*
  - *Aeration*

DP INS trials – **cardinal point calibration trajectory**
- 26. October 2008, Trondheim, Norway

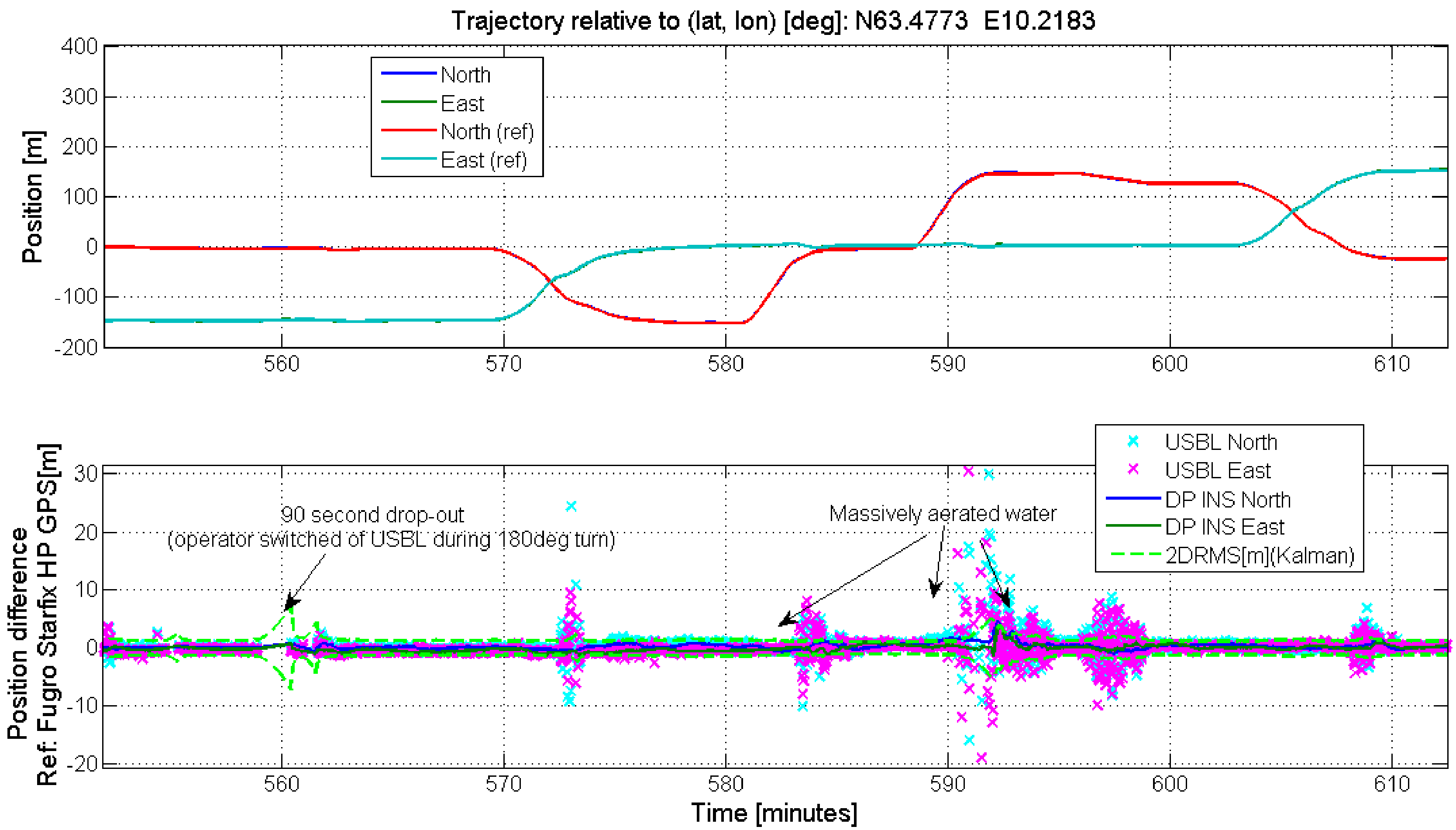


Attempt at worst case acoustic scenario !!!

- **Noise and aeration purposely maximised to push limits in moderate water depth (500m)**
- 5 locations
- Maximum thrust during transit and heading change.
- Significant aeration when coming to a halt

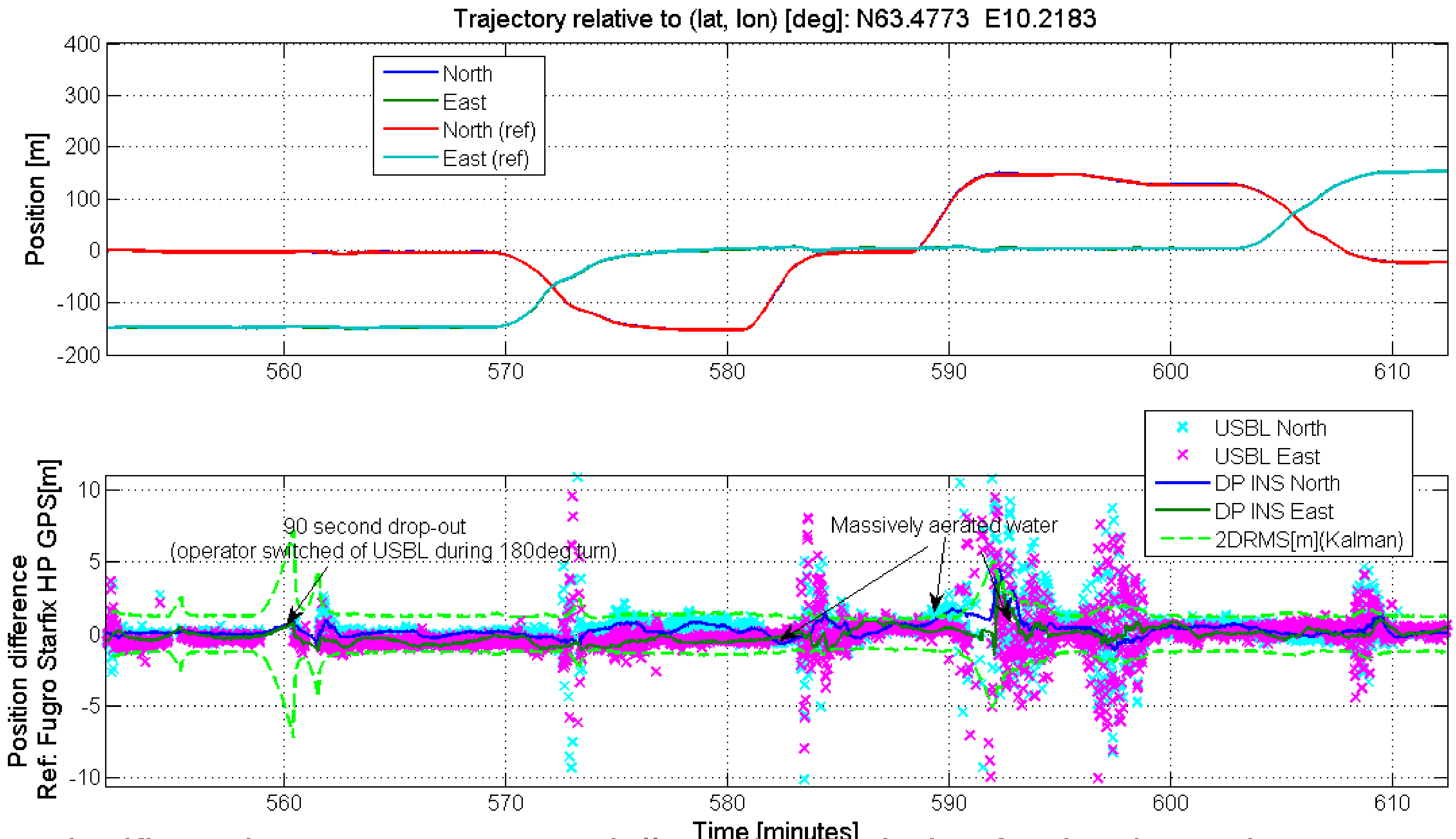
DP INS trials – **cardinal point calibration trajectory**

- 26. October 2008, Trondheim, Norway



- aeration primarily caused by excessive thruster power when vessel is coming to a halt in combination with shallow deployment of the USBL transceiver

DP INS trials – **cardinal point calibration trajectory**
- 26. October 2008, Trondheim, Norway

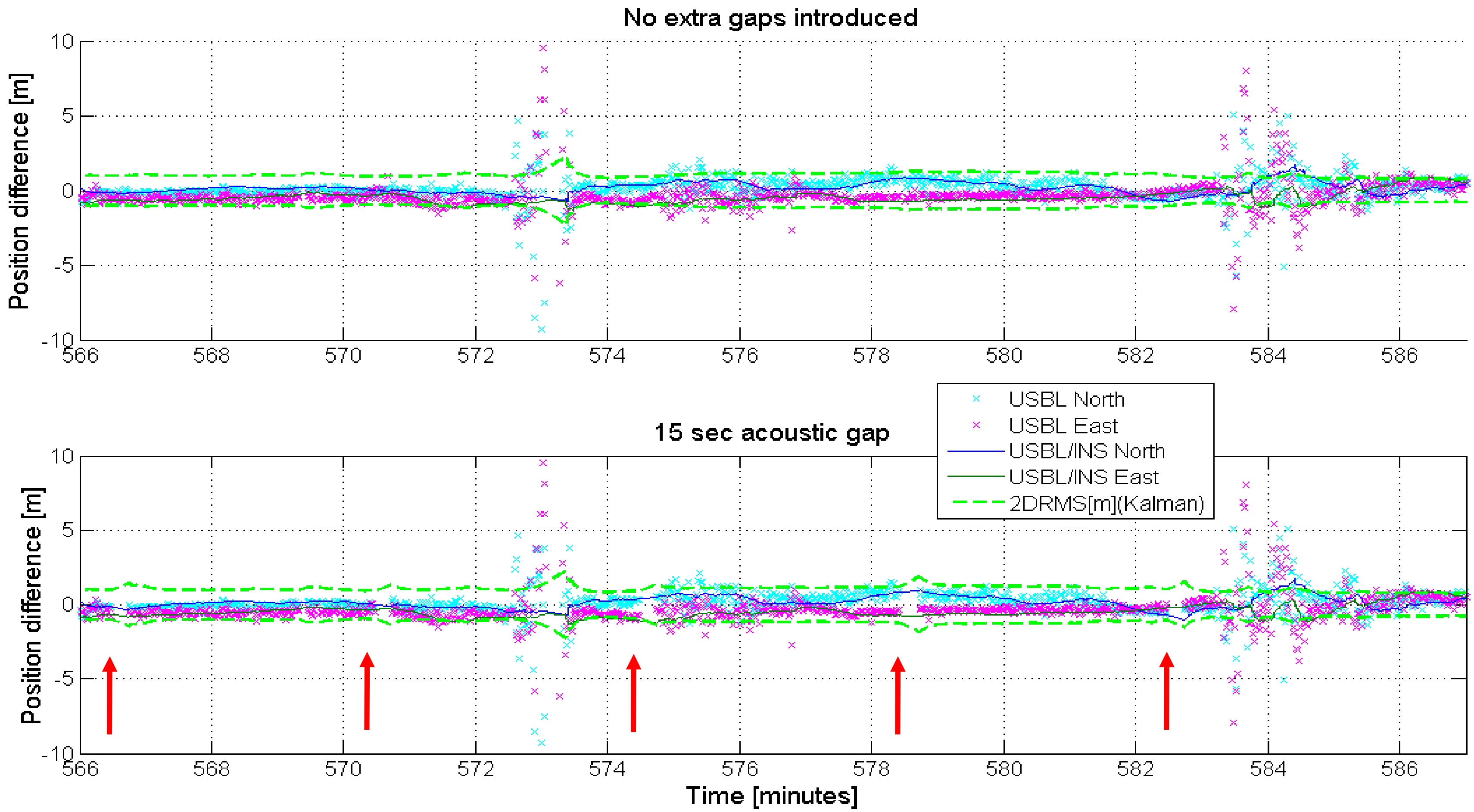


• Significant improvement especially during periods of noise / aeration.

• Aeration typically took 30 -120 seconds to die out when stationary.

DP INS trials – **acoustic drop out: 0 + 15 sec**

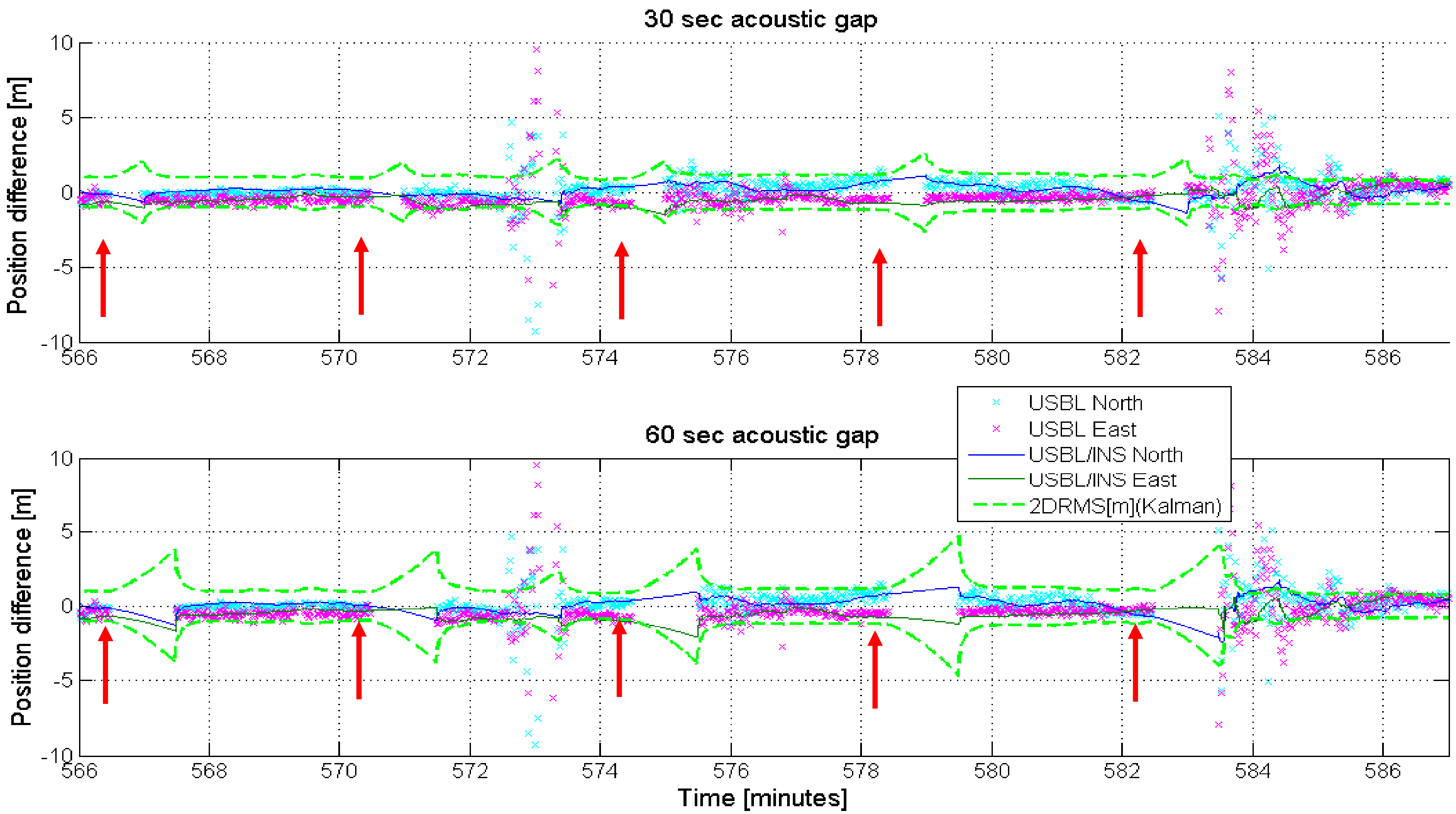
- 26. October 2008, Trondheim, Norway



- Introduction of 5 extra gaps in the data set
- No significant difference with sequence of 15 sec gaps

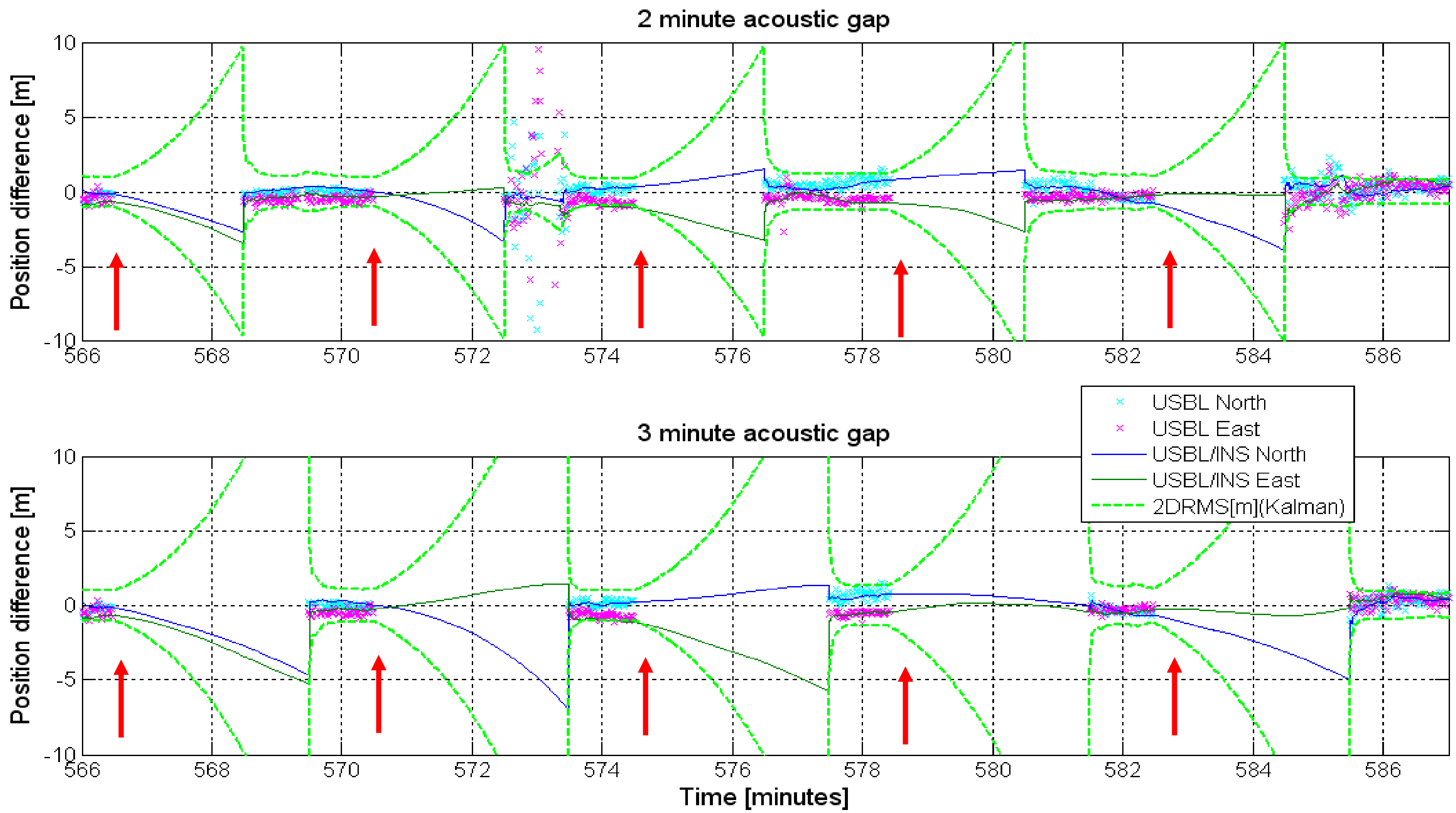
DP INS trials – **acoustic drop out: 30 + 60 sec**

- 26. October 2008, Trondheim, Norway



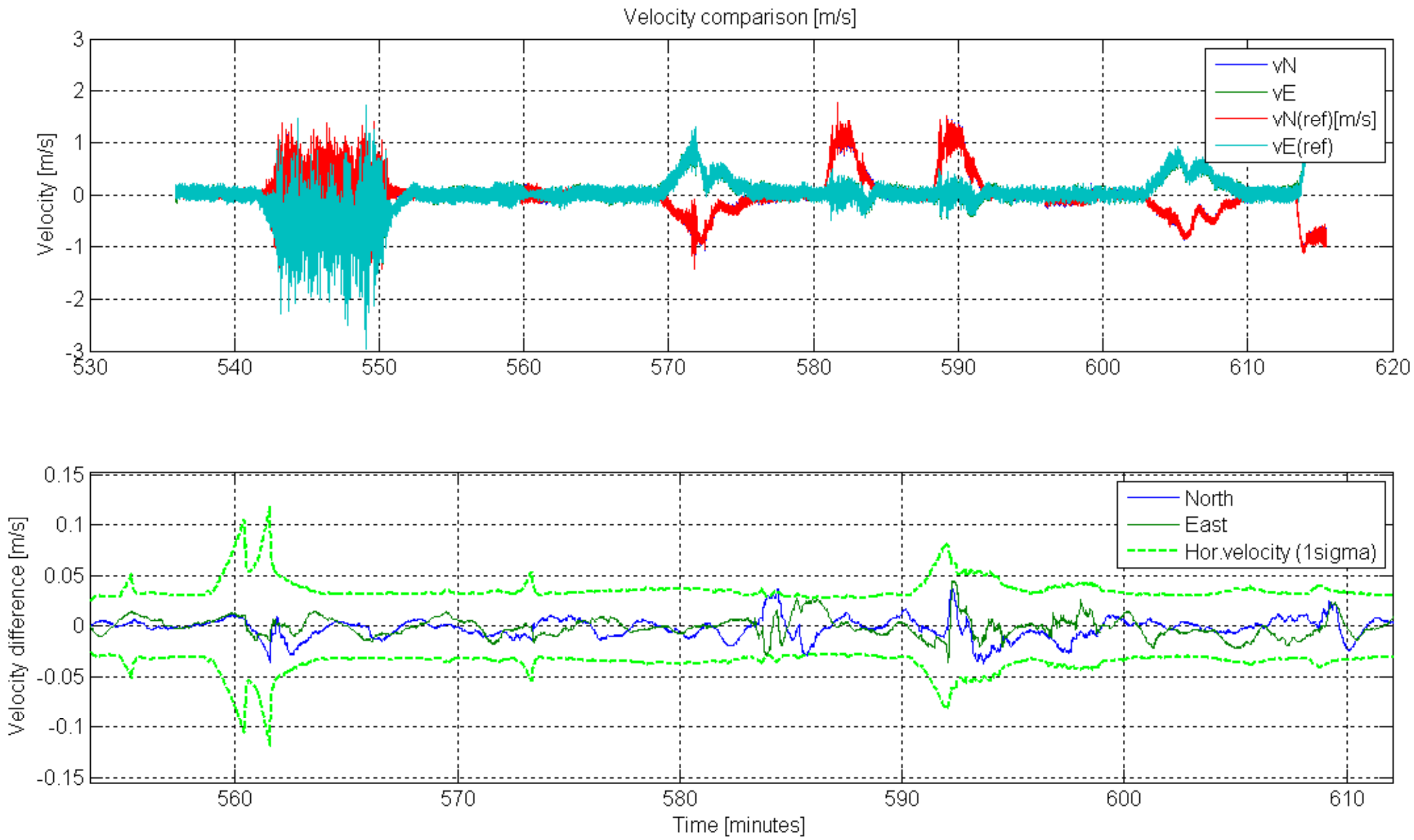
- 30 sec: Beginning to see slight drift
- 60 sec: Drift ~0.5m to 2m, about time system should raise an alarm?

DP INS trials – **acoustic drop out: 2 and 3 minutes**
- 26. October 2008, Trondheim, Norway



- 2 minutes: Drift to just above 3m per axis, 2DRMS larger
- 3 minutes: Peak drift 7m

DP INS trials – accurate velocity
- 26. October 2008, Trondheim, Norway



- DP INS provides a **very precise independent measurement of velocity**
  - accuracy is dependant on acoustic observations but typically few cm/s.
- **Velocity, angular rate and acceleration are valuable quantities for control** !

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Summing it up
-Benefits of DP INS

1. DP INS provides an alternative to LUSBL and DGPS
   Different concepts
   - LUSBL: Rich acoustics and redundancy
   - DP INS: Utilising the complementary characteristics of USBL and INS

2. Key DP INS features
   - Improved weighting against DGPS in DP desk
   - Ride through capability - most acoustic drop outs are **short lived**
   - Simple and cost efficient installation and operation
   - Expected to achieve 1-2m accuracy in deep water (2000m+)
   - Position update rate1-2 Hz independent of water depth

3. Tight coupling based on good control of all technologies
   - Mechanical – stability needed between INS and USBL transceiver
   - Electrical: No latency and simple installation
   - Fusion of raw acoustic observation and IMU data

4. Does DP INS qualify as a third independent reference?

The End

A quick note on tightly vs loosely integrated INS

The terms *tightly* and *loosely* coupled INS are often used inconsistently.

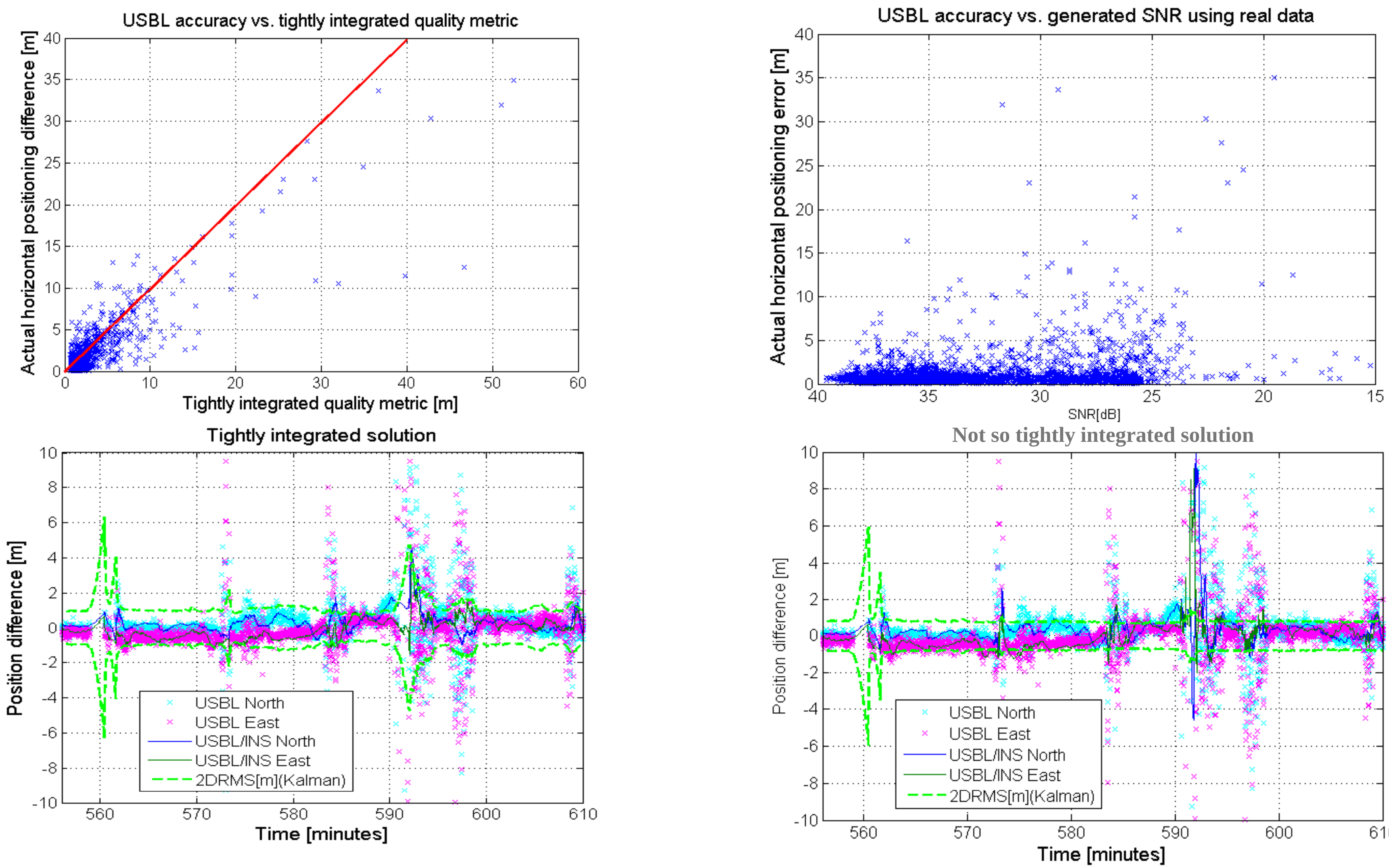
Their origin is GPS/INS where *loose integration* referred to use of GPS position and *tight integration* referred to use of raw pseudo range observations etc. Theoretically tight integration provides better performance but often will require more engineering and increase the design complexity.

With current Wideband USBL transceivers, the Lodestar INS makes use of phase and travel time information rather than acoustic position as computed by a USBL system. More importantly, raw acoustic and inertial information is combined and filtered to adaptively weight observations. Sonardyne refers to this as “tightly integrated USBL”. Integration will become even tighter in the future as a means to ensure performance and integrity especially under non-ideal acoustic conditions.

A quick example follows for illustration purposes only.

Data to the left is processed using the “tightly integrated” solution including a “tightly integrated” adaptive noise model. To be fair, the loosely coupled solution to the right could be improved by use of a better conventional noise model but would struggle to reach same performance and integrity under difficult acoustic conditions.

A quick note on tightly vs loosely integrated INS



System components: Marksman LUSBL

Backwards Compatible - Fast and simple to upgrade.

- Works with existing installed GDT USBL transceivers.
- and C5 Wideband transponders.
- Uses existing wiring
- Replaces Dimona HW and SW
- Can be installed without recalibration of existing GDT transceivers